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Evaluation of Restraint System Concepts for the Japanese Experiment Module Flight Demonstration

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Summary

The current International Space Station Alpha (ISSA) configuration includes a Japanese Experiment Module (JEM) which will rely on a large manipulator and a smaller dexterous manipulator to perform operations outside the pressurized environment of the JEM. The JEM flight demonstration (JFD) is a payload designated to fly aboard STS-87 with the objective of evaluating a prototype of the JEM dexterous manipulator. Since the JFD payload operations entail two 8-hour scenarios on consecutive days, adequate restraint of the operator at the JFD workstation—mounted in the Orbiter aft flight deck (AFD)—will play a critical role in the perceived success or failure of the payload. In experiments aboard the KC-135A aircraft, personnel from the Remote Operator Interaction Laboratory at NASA's Johnson Space Center evaluated two restraints: the Advanced Lower Body Extremities Restraint Test (ALBERT) and a foot loop restraint system. Simulating typical JFD operations in the reduced gravity environment provided by the KC-135A was the only way to adequately evaluate the restraint systems and also address issues of workstation configuration.

Two astronaut and two non-astronaut operators performed representative JFD tasks at a simulated workstation consisting of all relevant components of the JFD AFD workstation. Procedures were for the operators to perform tasks in each of the two restraint systems. At the conclusion of each flight, the operators filled out a questionnaire giving their impressions of each restraint system and the overall workstation configuration.

The workstation configuration could be improved. Access to the payload switch panels was difficult, and manipulation of the workstation hand controllers forced the operators too low for optimal viewing of the AFD monitors. It is recommended that the workstation panel be angled for better visibility and that only infrequently used switches be located on the AFD panel. It is also recommended that the pitch angle and location of the hand controllers be placed to optimize the operator's eye position with respect to the AFD monitors.

The ALBERT restraint was preferred over the foot loops because it allowed operators to maintain a more relaxed posture which would be less fatiguing during long-duration tasks. Its height adjustability allowed for better viewing of the AFD monitors and provided better restraint for reacting forces imparted on the operator at the workstation. For JFD operations, the foot loops would still provide adequate restraint for the tasks identified. However, since results from the JFD payload will impact the design of the JEM ISSA workstation, both restraints should be flown and used during operation of the JFD payload in order to evaluate the effect of restraint during the performance of long-duration tasks.

1. INTRODUCTION

The current ISSA configuration includes a module from Japan's National Space Development Agency (NASDA). This module (called the JEM) will have an attached exposed facility and exposed section, each of which will accommodate orbit replaceable units designed to be exchanged by either the JEM remote manipulator system (JEMRMS) which is attached to the JEM or by the small fine arm (SFA) which will be grappled and positioned by the JEMRMS. The JFD is a payload designated to fly aboard STS-87 to test a prototype of the SFA mounted in the Shuttle payload bay. The prototype manipulator will be controlled from an operator workstation in the Shuttle's AFD. Figure 1 shows a conceptual configuration of the operator workstation in the AFD.

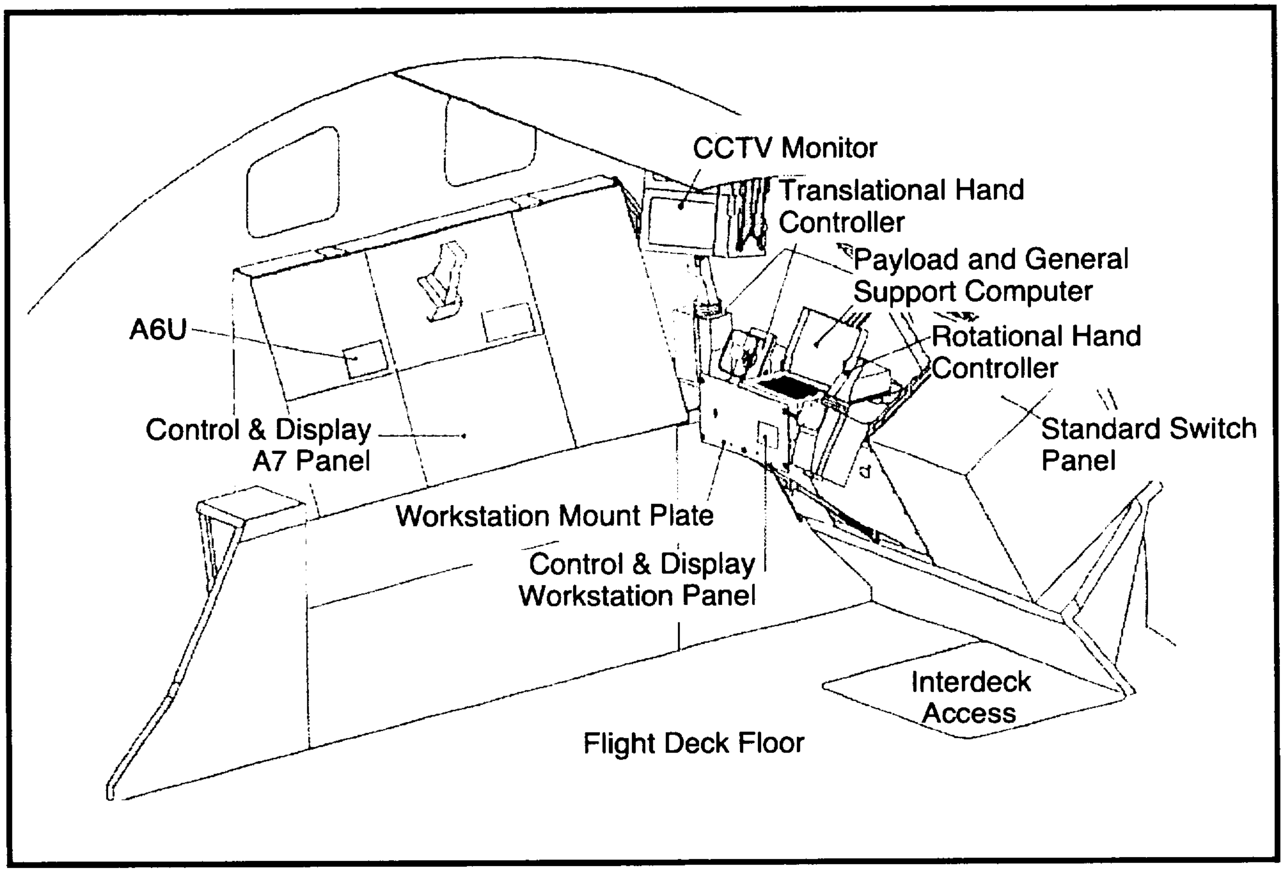


Figure 1. Conceptual orientation of JFD AFD workstation.

Proposed in-flight operations for the JFD payload entail two 8-hour operational scenarios on consecutive days. Due to cumulative operator fatigue over such a long series of tasks, adequate restraint of the operator will play a critical role in the perceived success or failure of the payload. As a result, the Flight Crew Support Division at Johnson Space Center funded an experiment performed by personnel from the Remote Operator Interaction Laboratory (ROIL) aboard the KC-135A aircraft. The primary objective of the experiment was to evaluate two operator restraint systems at a simulated JFD AFD workstation. The restraint systems evaluated were the Advanced Lower Body Extremities Restraint Test (ALBERT) and a foot loop restraint system similar to those typically used on orbit. The ALBERT system was flown aboard STS-51 in September 1993 and is to fly on STS-66 in November 1994. Crew opinions of the ALBERT were quite favorable. Further investigation regarding the possibility of using the ALBERT on STS-87 during JFD operations was therefore merited. A secondary objective of this experiment was to assess the

overall workstation configuration by evaluating the orientation of the workstation components with respect to each other and how well the operator could access each component while performing a typical task. Evaluation of the restraint systems was the primary objective because they could only be evaluated in the zero gravity environment provided by the KC-135A aircraft. Since the workstation configuration could, to a large extent, be evaluated on the ground, the workstation configuration was evaluated primarily with respect to how well operators could access the different components while in each of the two restraint systems.

2. METHODS

The following methods were employed in this evaluation.

2.1 Operators. Four operators participated in this evaluation: two astronauts and two non-astronauts. The non-astronaut operators had extensive experience in conducting experiments aboard the KC-135A, in participating in restraint system evaluations, and in performing remote manipulator-type operations. Therefore, it was felt that the non-astronaut data would complement any astronaut data collected.

2.2 Apparatus. This evaluation was performed aboard the KC-135A aircraft which is operated by the Reduced Gravity Program (part of Johnson Space Center). By flying a series of parabolic maneuvers, the aircraft provides a reduced gravity environment of less than one-gravity acceleration. For this flight, the maneuvers flown simulated zero gravity for periods of approximately 23 seconds at a time. The parabolic path for simulating zero gravity is shown in Appendix A. The two restraint systems are shown in Figure 2.

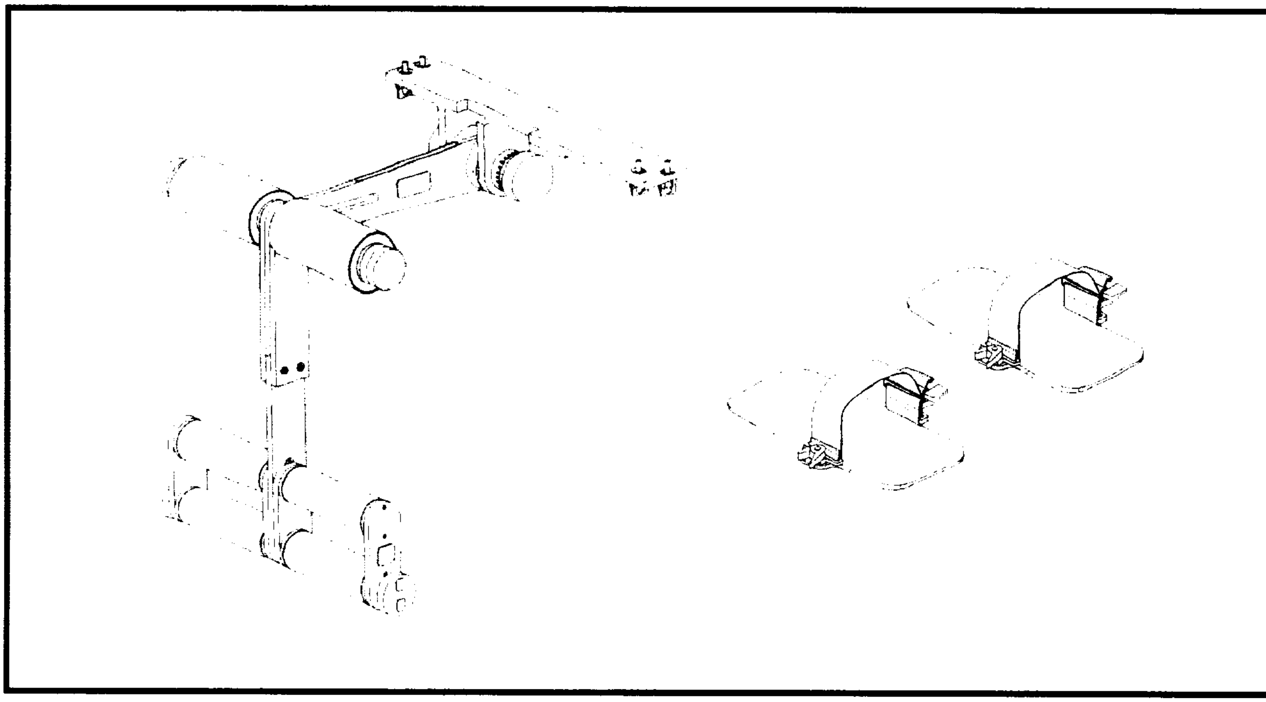


Figure 2. Isometric views of the ALBERT and the foot loop restraint system.

To implement the foot loop restraint, the operators simply slid their feet into the loops to maintain their position. Implementation of the ALBERT restraint is not quite as clear. Figure 3 shows a side view of an operator in the ALBERT system.

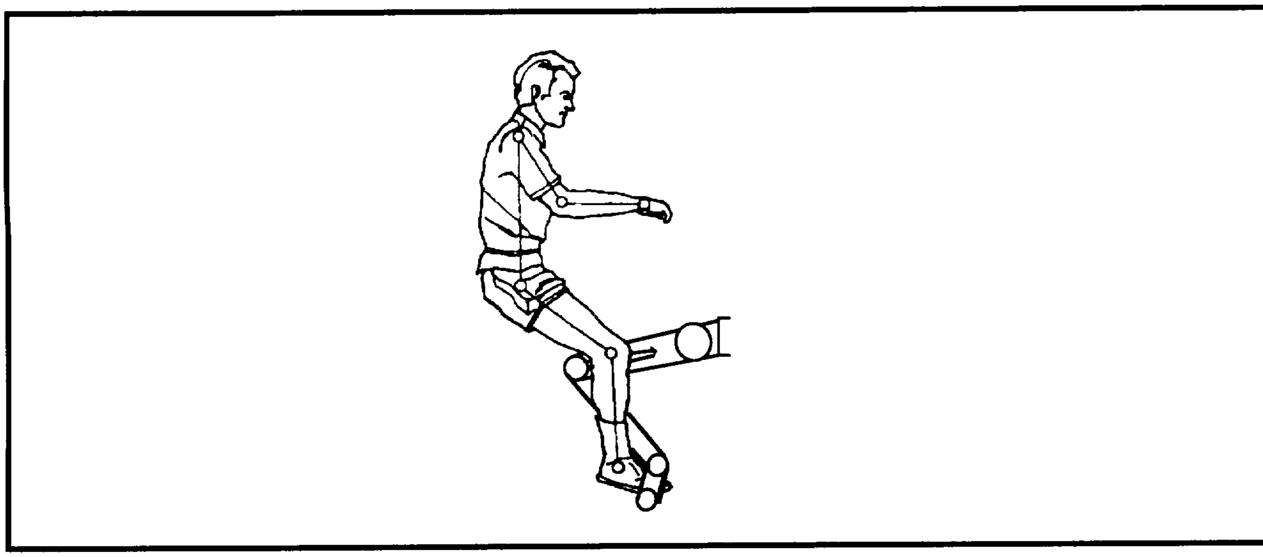


Figure 3. A 50th percentile male in the ALBERT restraint system (note that an operator can maintain a relaxed neutral body position while in the restraint).

The restraint systems were evaluated at a simulated JFD AFD workstation mounted on board the KC-135A aircraft. Figure 4 shows side and front views of the workstation. All relevant components with respect to proposed JFD operations were mocked up. These included the A7 switch panel, the workstation switch panel, the translational and rotational hand controllers, and a display mounted in the relative position of the upper AFD closed circuit television (CCTV) monitor. At the time of this evaluation, the JFD workstation concept incorporated height adjustability for the hand controllers and workstation panel. Incorporation of height adjustability for this experiment, however, was not feasible due to procedural constraints. Consequently, the height of the hand controllers and workstation panel were fixed at a position midpoint between the proposed range of adjustability.

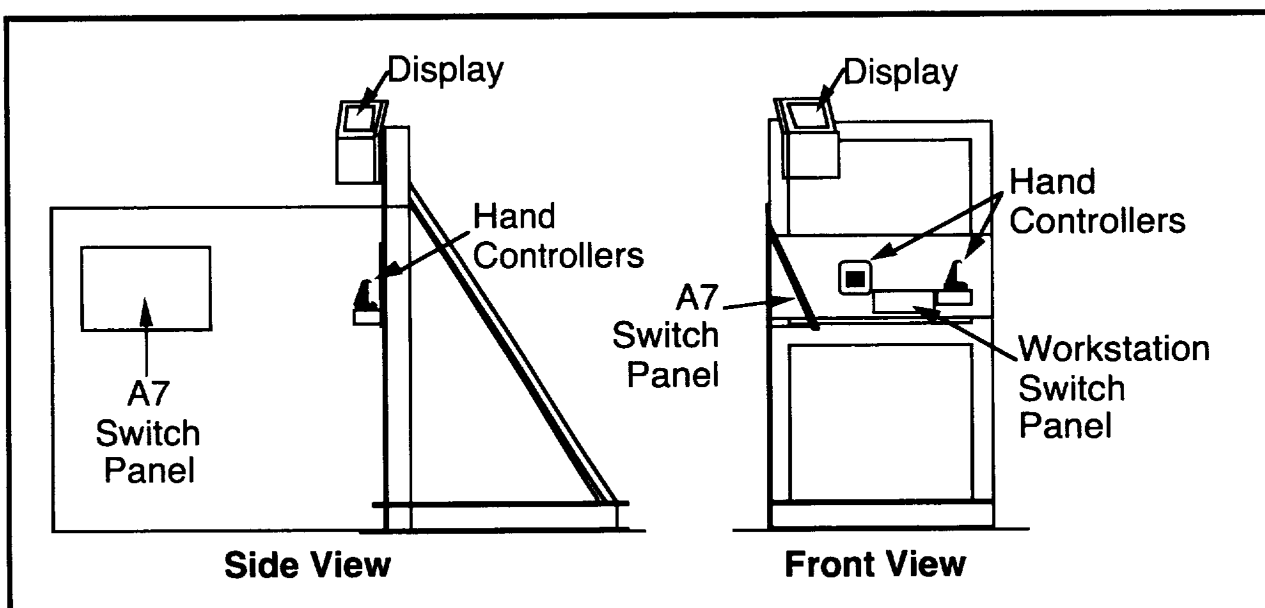


Figure 4. Side and front views of the workstation rack configuration used aboard the KC-135A for this experiment.

Both the A7 and workstation switch panels were foamcore cutouts with printed switches and buttons. The translational hand controller (THC) was a mockup with a controller handle and guard identical in size and shape to the flight article. A mockup was considered acceptable for the THC because the guard around the controller handle allows forces applied to the controller to be reacted locally, thus not placing any burden on the operator's body or the restraint system. Inputs to the rotational hand controller (RHC), however, do result in forces being applied to the operator and consequently onto the restraint system. As a result, for this evaluation, the RHC was an active controller commanding an active force/moment display. This display was shown on a notebook computer display mounted in the AFD upper CCTV monitor position.

2.3 Procedures. Once the KC-135A had reached the portion of the parabola achieving zero gravity, the operator's task was to enter the restraint and, at random, perform one of three tasks. These included nulling out preset forces and moments on the display using the active RHC, and accessing the workstation and A7 switch panels (i.e., visually acquiring the panel and simulating operation of the printed switches). Operators were instructed to vary the sequence and amount of time spent performing each of the three tasks. Each operator performed these tasks a number of times in each of the two restraints. (The number of parabolas the operators spent in each restraint could not be predetermined since the parabola profile was defined and altered in flight according to the needs of another, primary experiment flying at the same time.) All four operators felt they had performed enough tasks in each restraint to adequately assess the two. At the conclusion of each flight, the operators filled out a questionnaire giving their subjective impressions of each restraint system and the overall workstation configuration. A copy of the questionnaire is included in Appendix B.

3. RESULTS

Given that data were only collected on four operators in this evaluation, a meaningful statistical analysis could not realistically be performed. Consequently, results were based on summarizing both the operators' comments and their numerical ratings to questionnaire items. To address the objectives of this evaluation, comments will be split regarding the workstation and the restraints. Table 1 clarifies the strengths and weaknesses for each of the restraints.

3.1 Workstation. General comments regarding the workstation configuration focused on accessibility of the two workstation panels and visibility of the display screen located at the upper AFD CCTV monitor position.

Access to either switch panel was not considered ideal with either restraint. The A7 switch panel was located far enough behind the operator that access to it required a good deal of effort. The workstation switch panel mounted perpendicular to the floor also presented access problems. Visibility of the switches was a problem and resulted in the operator expending some effort to crouch low enough to see and activate the switches. Reach was not a problem.

Visibility of the display screen was also not ideal with either restraint. If the operator raised himself or herself high enough that the view of the display was acceptable, the position of the hand controllers was too low for optimal control.

3.2 Restraint. Comments regarding the two restraint systems focused on the ability of operators to maintain their body position while using the RHC, on accessibility to the two switch panels, and on ability to view the display screen.

Written comments from all operators expressed a clear preference for the ALBERT over the foot loops for maintaining body position while using the RHC to nullify forces on the display. Operators mentioned that use of the ALBERT would likely be less fatiguing during the performance of long-duration tasks. Numerical ratings from the non-astronauts reflected this preference while the astronaut ratings did not.

Written comments regarding accessibility to the two switch panels did not differ greatly between the two restraint systems. Numerical ratings from the operators, however, did show a slight preference for the ALBERT over the foot loops.

Comments from all operators again showed a preference for the ALBERT in terms of ability to view the display screen. The height adjustability of the ALBERT allowed for better viewing position optimization. The numerical ratings also expressed this slight, but consistent preference for the ALBERT over the foot loops.

Table 1. Relative Pros and Cons of the ALBERT and Foot Loop Restraint Systems

	PROS	CONS
ALBERT	• Allows operator to maintain a more relaxed neutral body posture likely to be less fatiguing during long-duration tasks. • Height adjustability is favorable for visibility of displays and out the window. • Provides good restraint during most hand controller inputs.	• Mounted volume takes up space in the crew compartment, possibly obstructing passage through the interdeck access. • Launch/landing stowage issues must be addressed.
Foot Loops	• Mounted volume takes up almost no space. • Operator can easily lower himself or herself to gain easier access to the workstation panel.	• Operators must stand to see the upper CCTV monitor and curl their toes to stay in the foot loops. This will be fatiguing over the course of a long-duration task. • Forces applied by the operator at the workstation are reacted only at the feet. This results in a long moment arm which is inefficient for reacting those forces.

4. CONCLUSIONS AND RECOMMENDATIONS

Given that comments and ratings focused on the workstation configuration and the restraint systems somewhat separately, conclusions and recommendations are similarly separated.

4.1 Workstation. The pitch angle and location of the hand controllers were not optimally placed. They were located too low for operators to adequately see the display while commanding the controller. Although this may have been partly a function of the lack of workstation adjustability in this experiment, the proposed range of the JFD workstation adjustability was not such that this problem would likely have been resolved. We recommend that the pitch angle and location of the hand controllers be placed so that the operator's eye position with respect to the AFD CCTV monitor is optimized. This optimal location can be determined on the ground prior to flight, and the mounting hardware can be appropriately modified. This could result in a sturdier workstation that would better adhere to safety requirements.

The workstation switch panel was also found to be poorly positioned. The location was low, and its orientation perpendicular to the flight deck floor hampered the operator's ability to access it. To improve

operator accessibility, we recommend that the height and orientation of the switch panel be optimized (raised and angled upward) on the ground prior to flight.

Access to the A7 panel was awkward using either restraint. Its position requires a good deal of effort for the operator to access. Prior to flight, operational analyses should be performed to ensure that only infrequently used switches and controls are placed on the A7 panel and that the frequently used switches are placed on the workstation panel.

4.2 Restraint. The results indicated that operators strongly preferred the ALBERT restraint over the foot loop restraint system. The ALBERT's range of adjustability made it suitable for a wider range of astronaut sizes and individual preferences regarding body posture on orbit. The data collected on the foot loops indicated that although they were seen as less effective than the ALBERT, they would still likely do an adequate job of restraining the operator for the JFD tasks identified. Fatigue, however, would probably be worse with foot loops than with the ALBERT. This could generate negative comments about the payload since it may not be clear to the astronaut whether poor performance was due to inadequate restraint or poor payload design. For these reasons and because the JFD payload results will impact the design of the JEM ISSA workstation, we recommend that both restraints be flown and used during operation of the JFD payload. This will provide a unique opportunity to evaluate the effect of restraint during the performance of long-duration tasks.

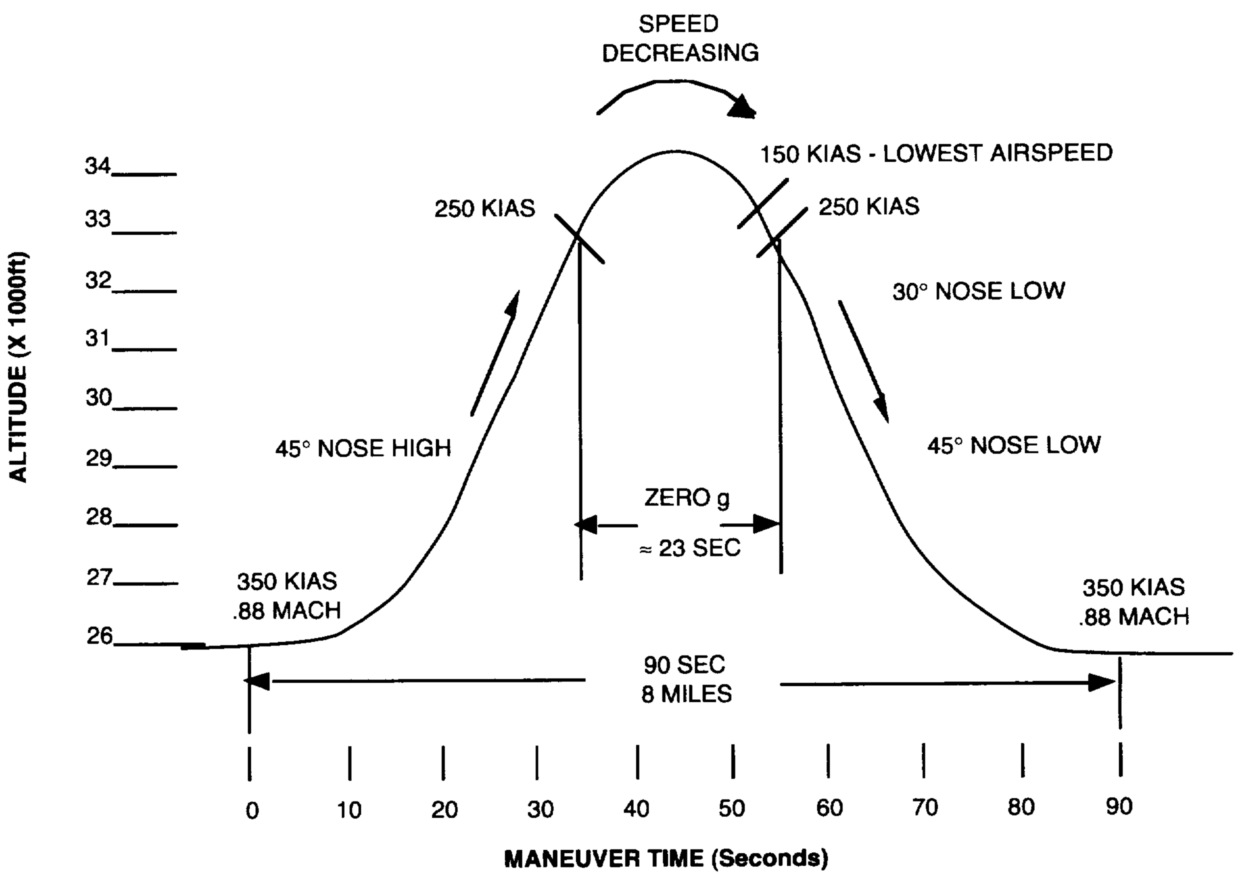
5. FUTURE WORK

Observations of typical workstation tasks in the KC-135A aircraft combined with findings from workstation evaluations which have taken place in the Full Fuselage Trainer (a full-scale mockup of the Shuttle's flight deck and middeck) have resulted in a thorough assessment of the overall JFD payload workstation operations. Information from these human factors evaluations have been discussed with NASDA engineers and have resulted in a modified system which we believe has resulted in an improved and safer user interface.

Future plans have been devised for ROIL personnel to determine the range of angular adjustability of the RHC, the optimal angle for the THC, the layout and location of control panels within the AFD, and the adequacy of various camera views. The ROIL will fabricate higher fidelity workstation mockups in support of these tests.

APPENDIX A

Parabolic Profile Used in KC-135A Microgravity Flights



Information supplied by the JSC Reduced Gravity Program

APPENDIX B

JFD AFD Workstation Restraint Evaluation Questionnaire

Operator: ____________________

Using the following rating scale, please respond to the questions below:

1	2	3	4	5	6	7
Completely Acceptable	**Reasonably Acceptable**	**Barely Acceptable**	**Borderline**	**Barely Unacceptable**	**Reasonably Unacceptable**	**Completely Unacceptable**

1. How acceptable were the restraints for maintaining your position at the workstation while trying to nullify forces on the display?

ALBERT __________

Foot Loops __________

Comments: ____

____

2. How acceptable was the restraint in helping to reduce problems with cross-coupling (please specify which axes presented problems)?

ALBERT __________

Foot Loops __________

Comments: ____

____

3. How acceptable was accessibility to the workstation switch panel?

ALBERT __________

Foot Loops __________

Comments: ____

____

4. How acceptable was accessibility to the A7 switch panel?

ALBERT __________

Foot Loops __________

Comments: ____

____

5. How acceptable was your ability to view the display screen?

ALBERT __________

Foot Loops __________

Comments: ____

____

6. On the back of this sheet, please comment on any modifications you feel can or should be made to improve the overall workstation arrangement.

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13. ABSTRACT *(Maximum 200 words)*

The current International Space Station configuration includes a Japanese Experiment Module which relies on a large manipulator and a smaller dexterous manipulator to operate outside the pressurized environment of the experiment module. The module's flight demonstration is a payload that will be mounted in the aft flight deck on STS-87 to evaluate a prototype of the dexterous manipulator. Since the payload operations entail two 8-hour scenarios on consecutive days, adequate operator restraint at the workstation will be critical to the perceived success or failure of the payload. Simulations in reduced gravity environment on the KC-135A were the only way to evaluate the restraint systems and workstation configuration. Two astronaut and two non-astronaut operators evaluated the Advanced Lower Body Extremities Restraint Test and a foot loop restraint system by performing representative tasks at the workstation in each of the two restraint systems; at the end of each flight they gave their impressions of each system and the workstation. Results indicated that access to the workstation switch panels was difficult and manipulation of the hand controllers forced operators too low for optimal viewing of the aft flight deck monitors. The workstation panel should be angled for better visibility, and infrequently used switches should be on the aft flight deck panel. Pitch angle and placement of the hand controllers should optimize the operator's eye position with respect to the monitors. The lower body restraint was preferred over the foot loops because it allowed operators to maintain a more relaxed posture during long-duration tasks, its height adjustability allowed better viewing of aft flight deck monitors, and it provided better restraint for reacting forces imparted on the operator at the workstation. The foot loops provide adequate restraint for the flight demonstration tasks identified. Since results will impact the design of the workstation, both restraints should be flown and used during operation of the flight demonstration payload to evaluate the effect of restraint during long-duration tasks.

14. SUBJECT TERMS

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